National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
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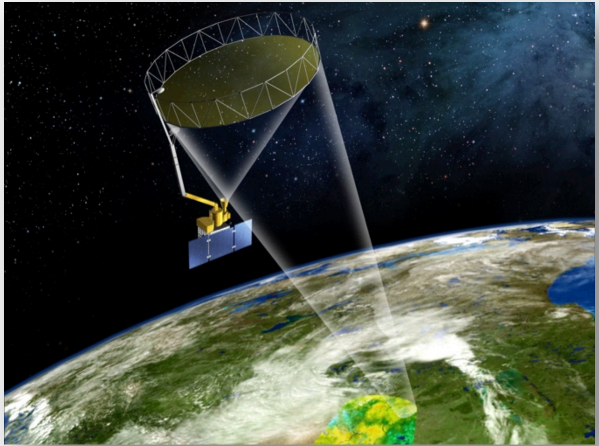
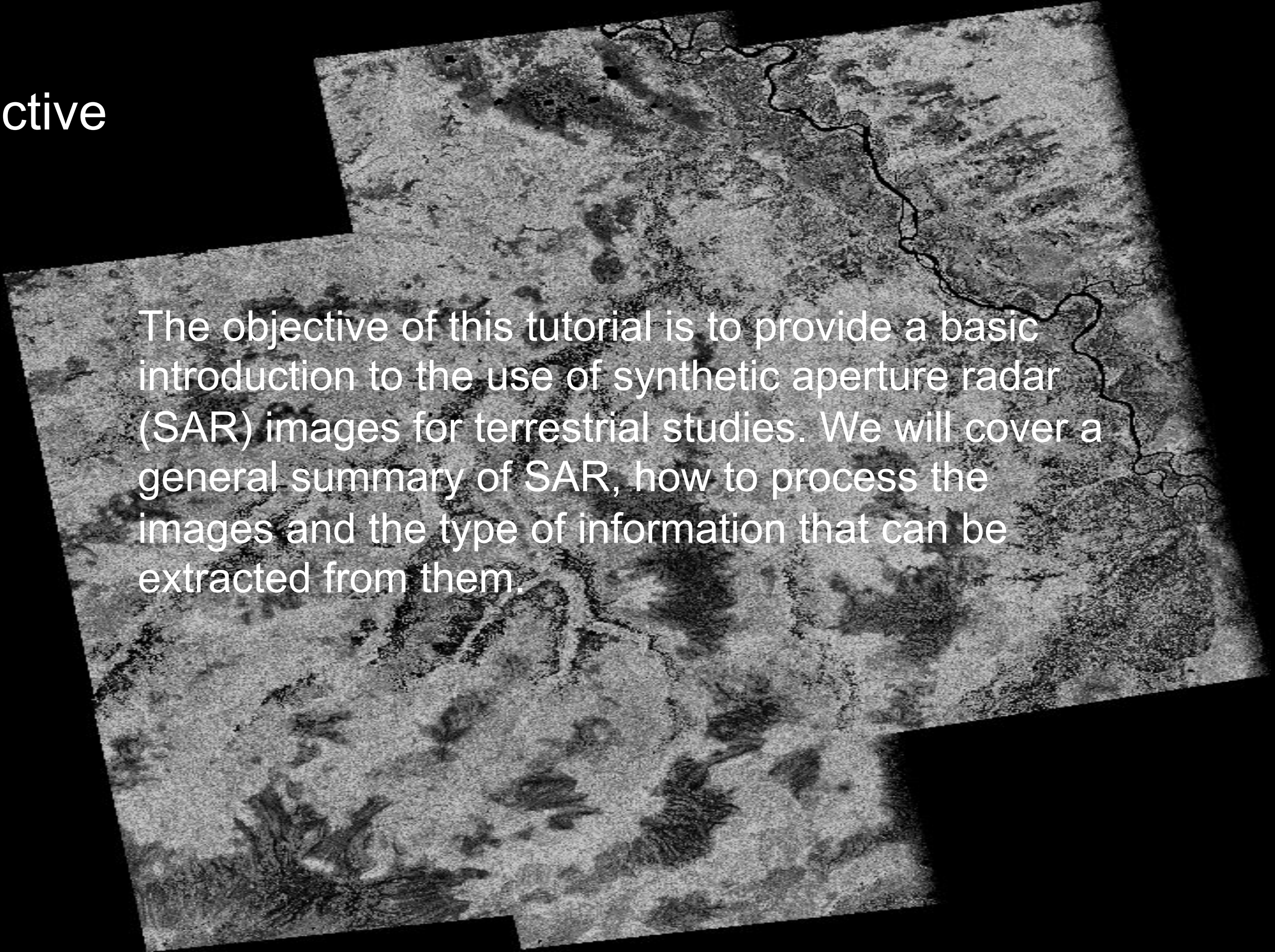
Introduction to Radar



Jul. 16, 2016

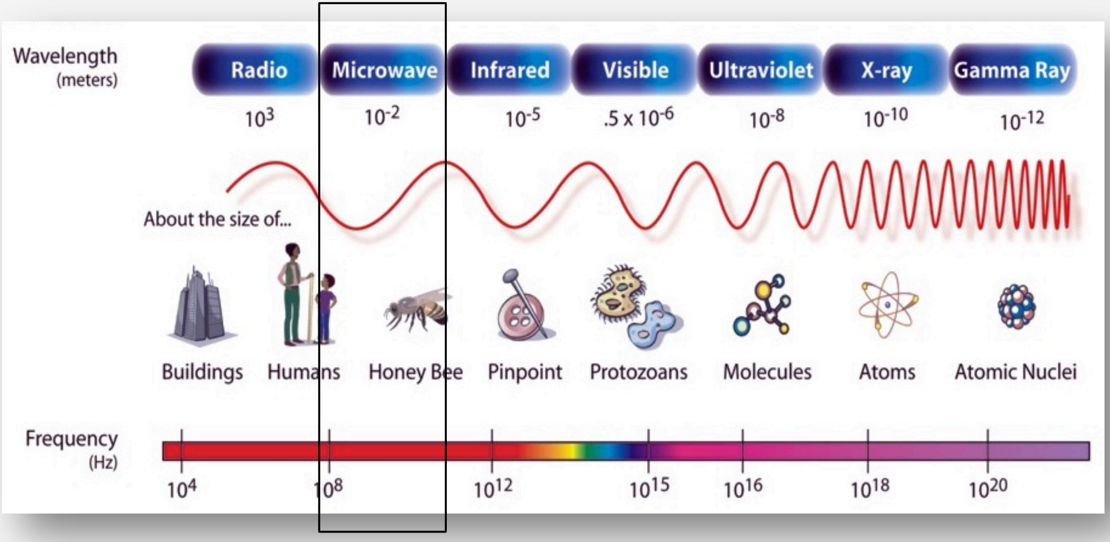
Objective



The objective of this tutorial is to provide a basic introduction to the use of synthetic aperture radar (SAR) images for terrestrial studies. We will cover a general summary of SAR, how to process the images and the type of information that can be extracted from them.

The Electromagnetic Spectrum

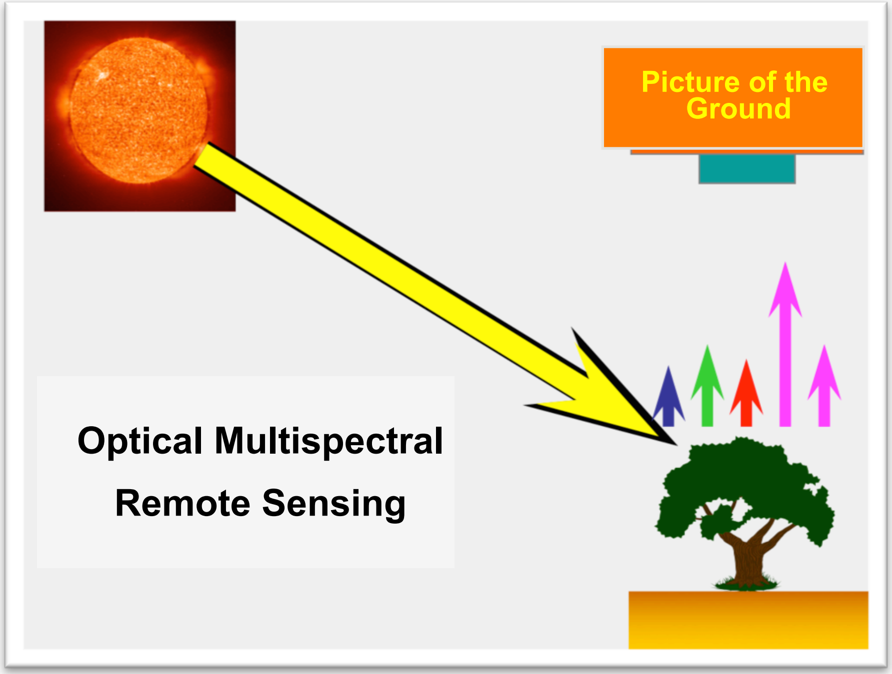
- The surface of the Earth cannot be imaged with visible or infrared sensors when there are clouds or when there is dense vegetation.
- Optical sensors measure reflected solar light and only function in the daytime.



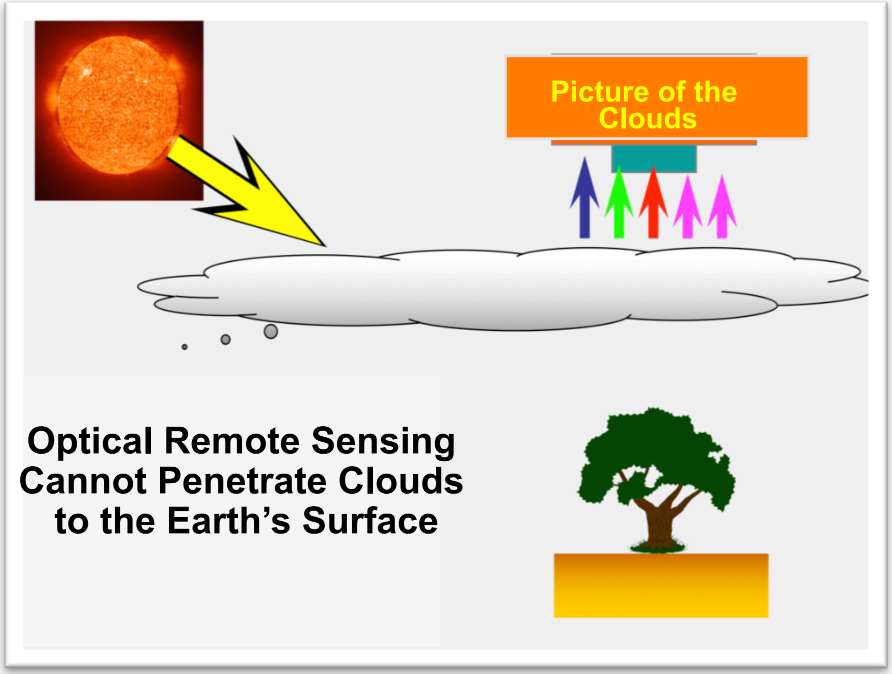
- Microwaves can penetrate clouds and vegetation and can operate in day or night conditions.

Optical Remote Sensing: Advantages and Disadvantages

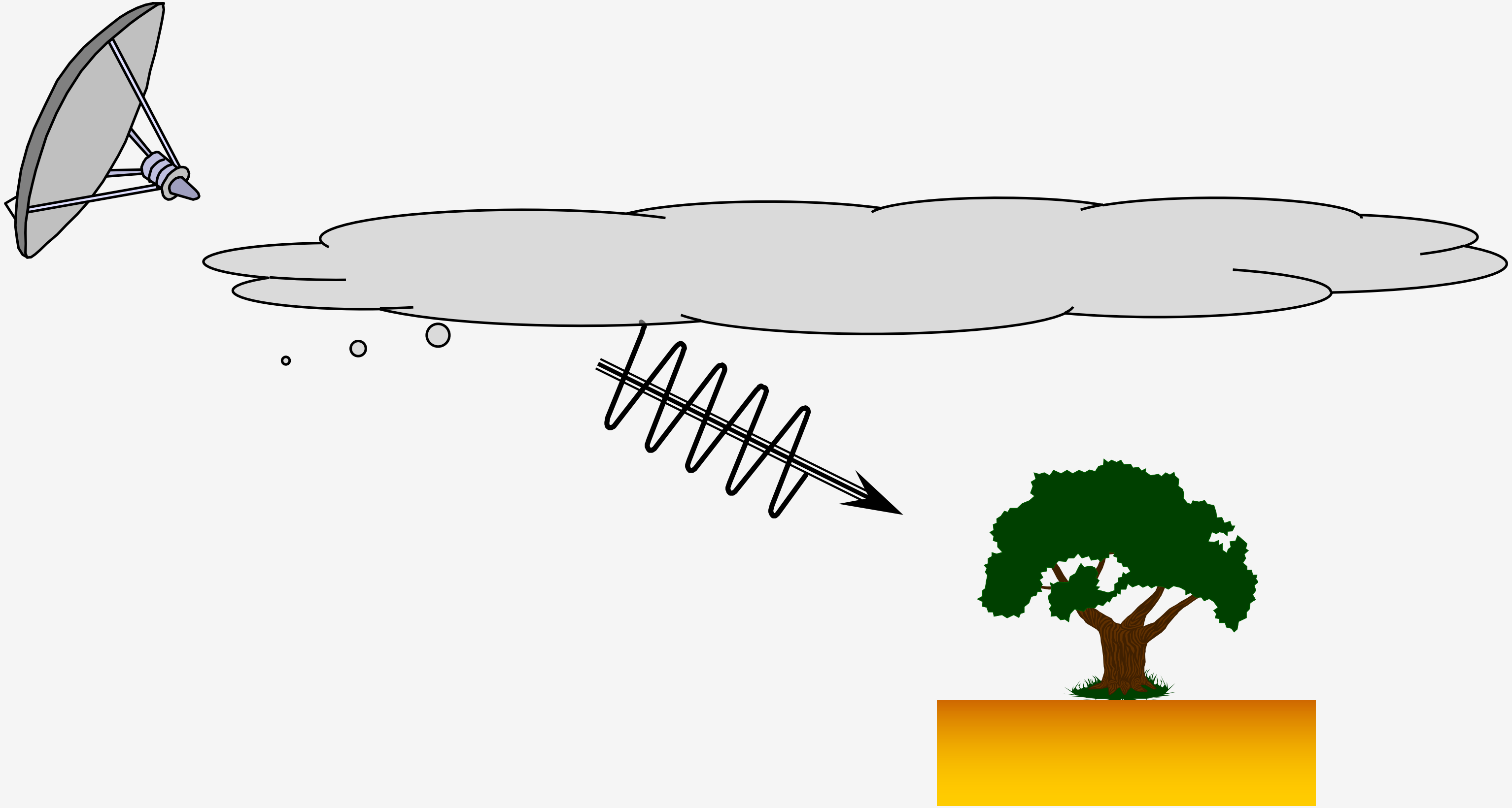
Advantages



Disadvantages

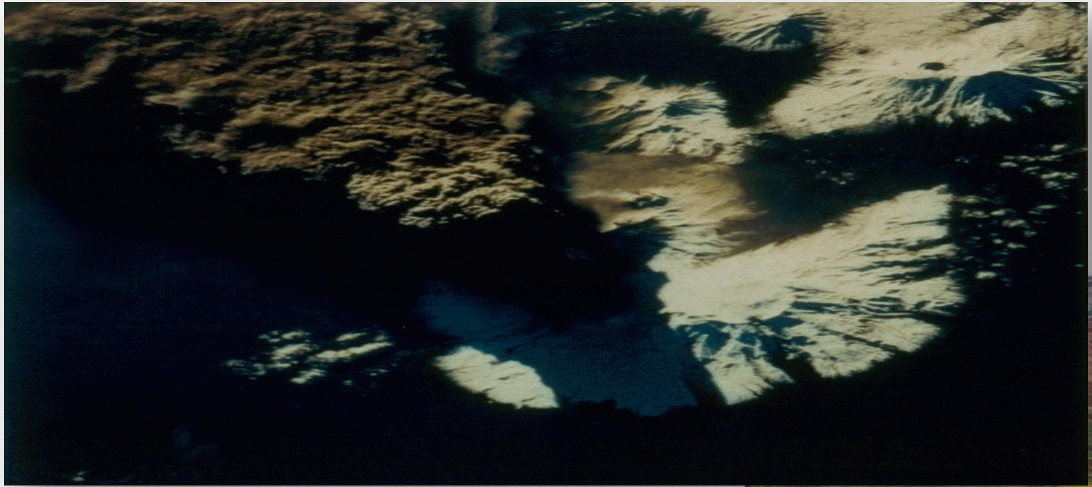


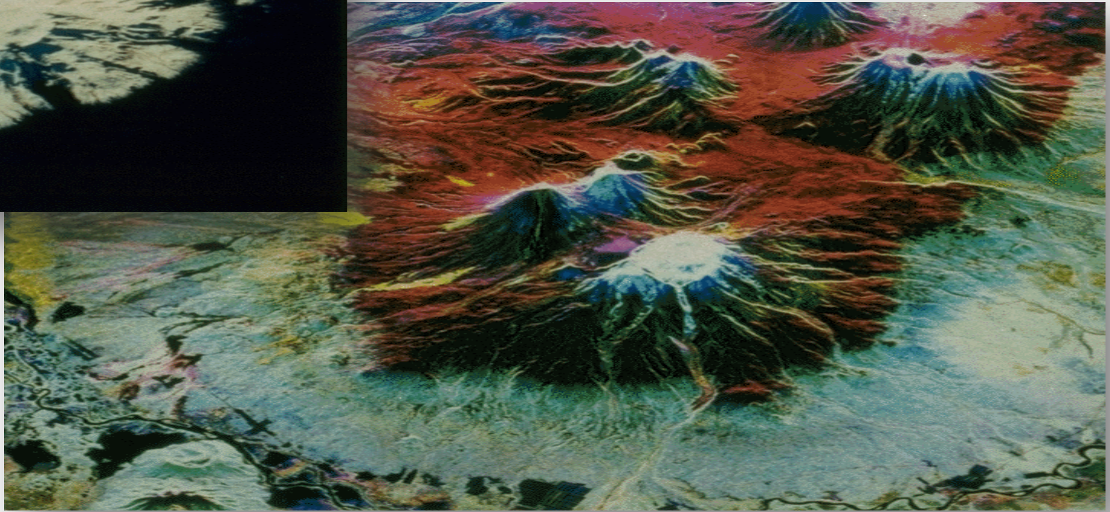
Radar: Advantages



Remote Sensing Example of Optical vs. Radar

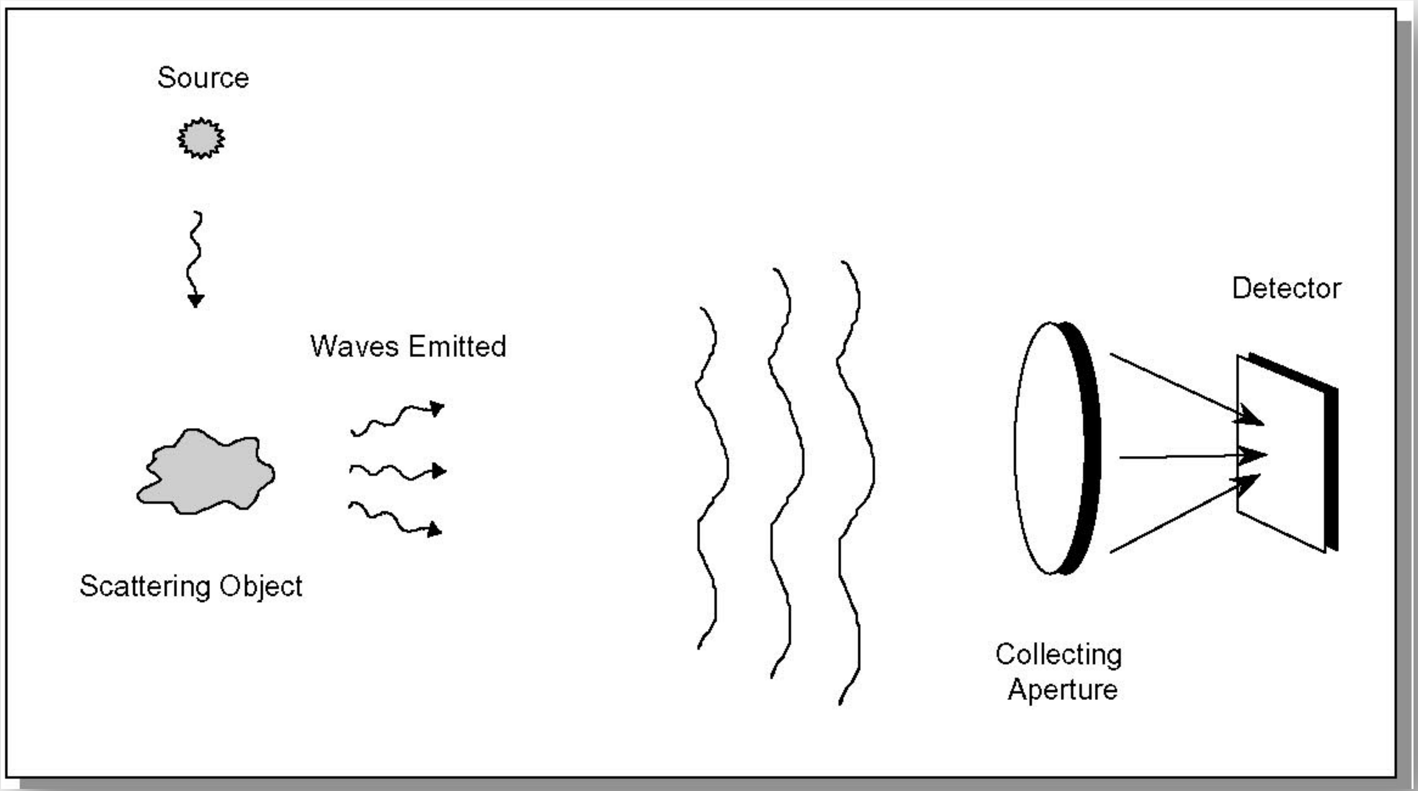
Volcano in Kamchatka, Russia





October 5, 1994

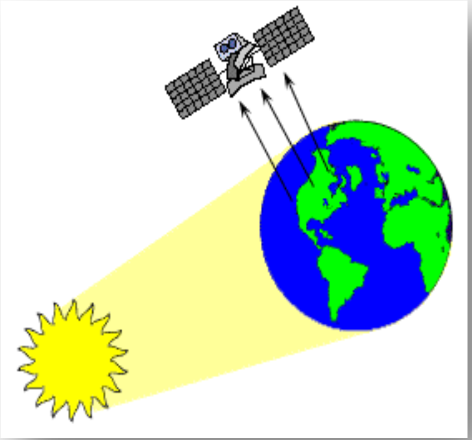
Basic Remote Sensing System



Teledetección de Sistemas Pasivos y Activos

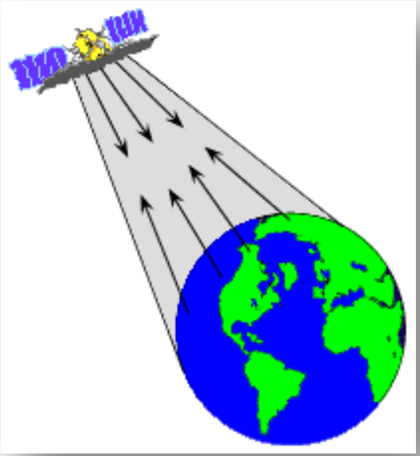
Passive Sensors:

The Source of radiant energy arises from natural sources … sun, earth, other “hot” bodies

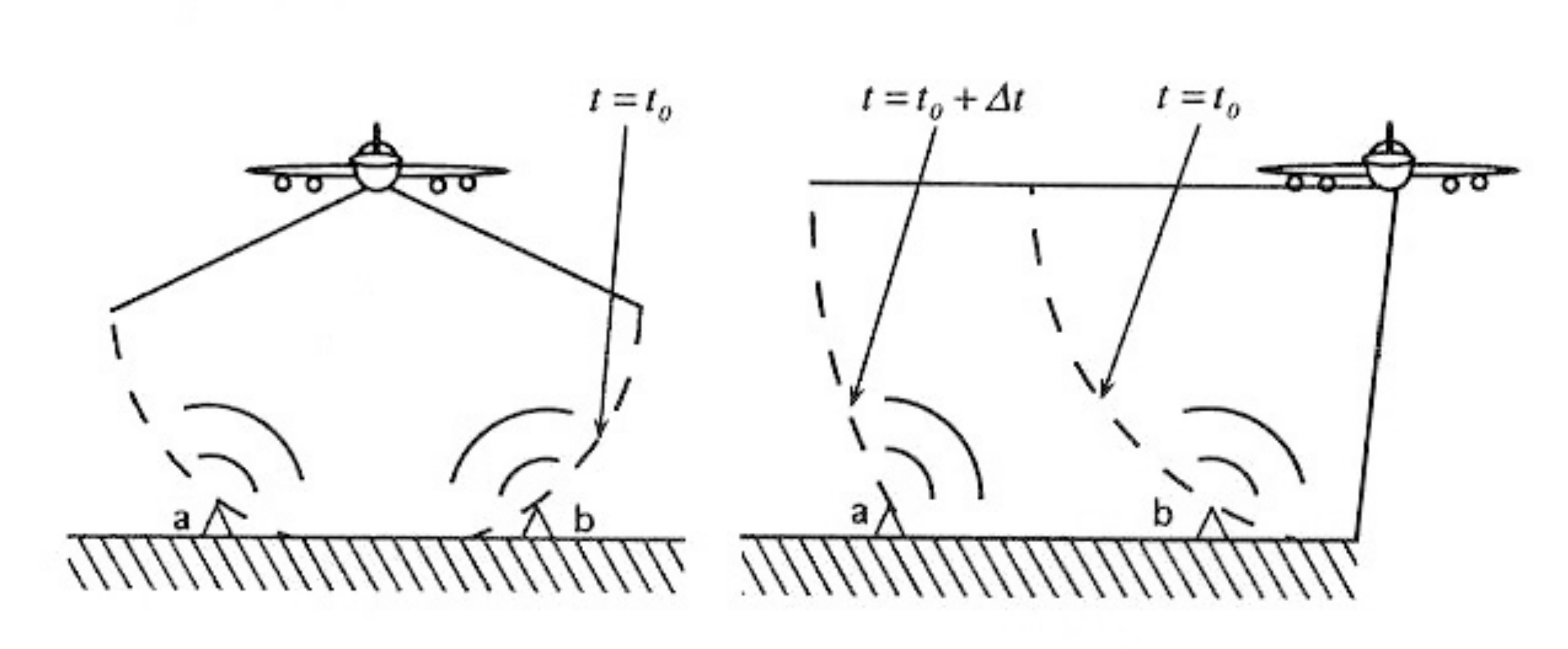


Active sensors:

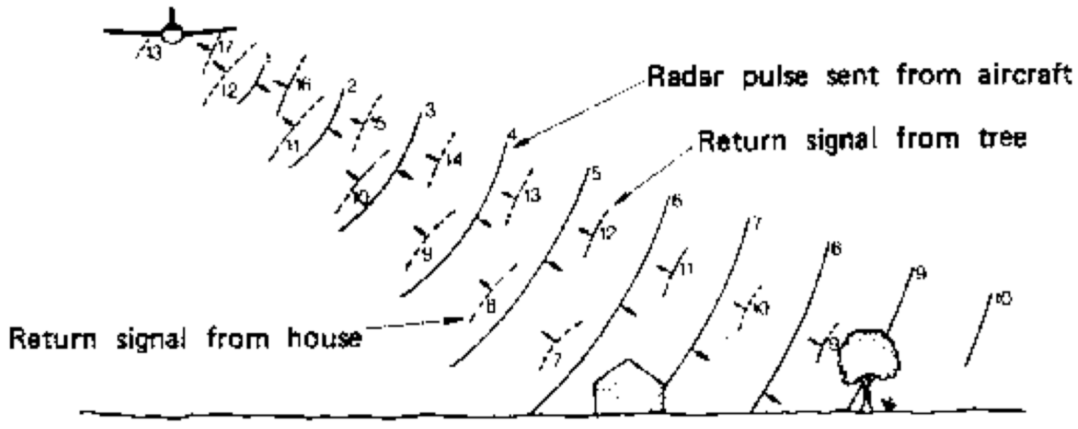
Provide their own artificial radiant energy source for illumination … **radar**, **synthetic aperture radar (SAR)**, LIDAR



Basic Concepts: Down Looking vs. Side Looking Radar



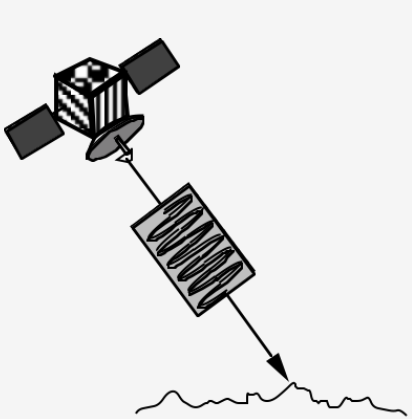
Basic Concepts: Side Looking Radar



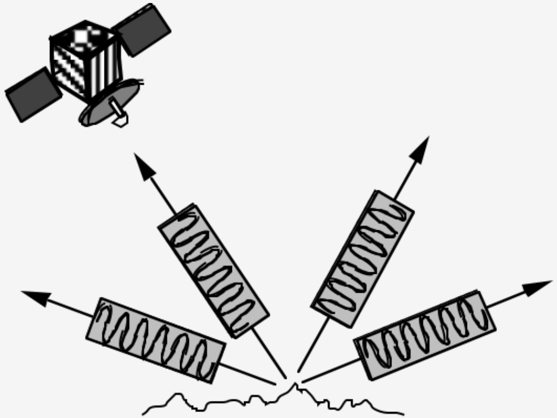
- Each pixel in the radar image represents a complex quantity of the energy that was reflected back to the satellite.
- The magnitude of each pixel represents the intensity of the reflected echo.

Review of Radar Image Formation

RADAR MEASUREMENTS



RADAR TRANSMITS A PULSE

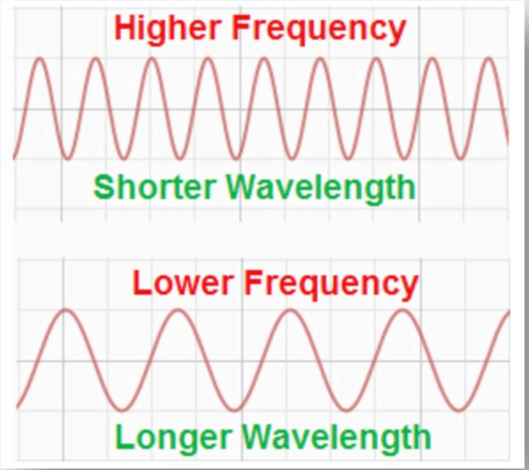


MEASURES REFLECTED ECHO (BACKSCATTER)

1. Radar can measure time delay and strength of reflected echo
   ==> amplitude and phase measurements
2. Radar can only measure part of echo reflected back towards the antenna (backscatter)
3. Radar pulses travel at speed of light
4. Time delay ==> ability to image objects at different ranges from radar (range resolution)
5. Strength (amplitude) of reflected echo is called radar backscatter

Radar Parameters: Wavelength

$$\text{Wavelength} = \frac{\text{Speed of light}}{\text{frequency}}$$



Band designation*	Wavelength (λ), cm	Frequency (ν), GH_z (10^9 cycles · sec^{-1})
Ka (0.86 cm)	0.8 to 1.1	40.0 to 26.5
K	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X (3.0 cm, 3.2 cm)	2.4 to 3.8	12.5 to 8.0
C (6.0)	3.8 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L (23.5 cm, 25 cm)	15.0 to 30.0	2.0 to 1.0
P (68 cm)	30.0 to 100.0	1.0 to 0.3

*Wavelengths most frequently used in radar are in parenthesis

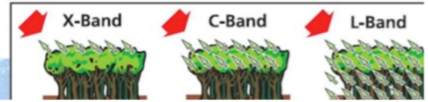
Radar Parameters: Wavelength

Penetration is the primary factor in wavelength selection

Penetration through the forest canopy or into the soil is greater with longer wavelengths

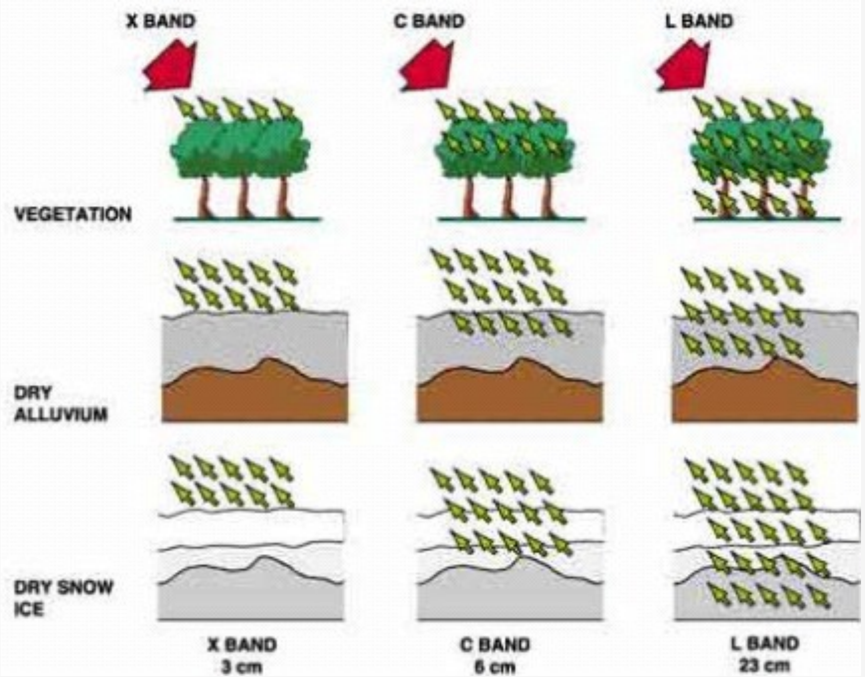
Commonly Used Frequency Bands

Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	biomass, soil moisture, penetration
• L-Band	1 GHz - 2 GHz	agriculture, forestry, soil moisture
• C-Band	4 GHz - 8 GHz	ocean, agriculture
• X-Band	8 GHz - 12 GHz	agriculture, ocean, high resolution radar
• Ku-Band	14 GHz - 18 GHz	glaciology (snow cover mapping)
• Ka-Band	27 GHz - 47 GHz	high resolution radars



Fuente: DLR

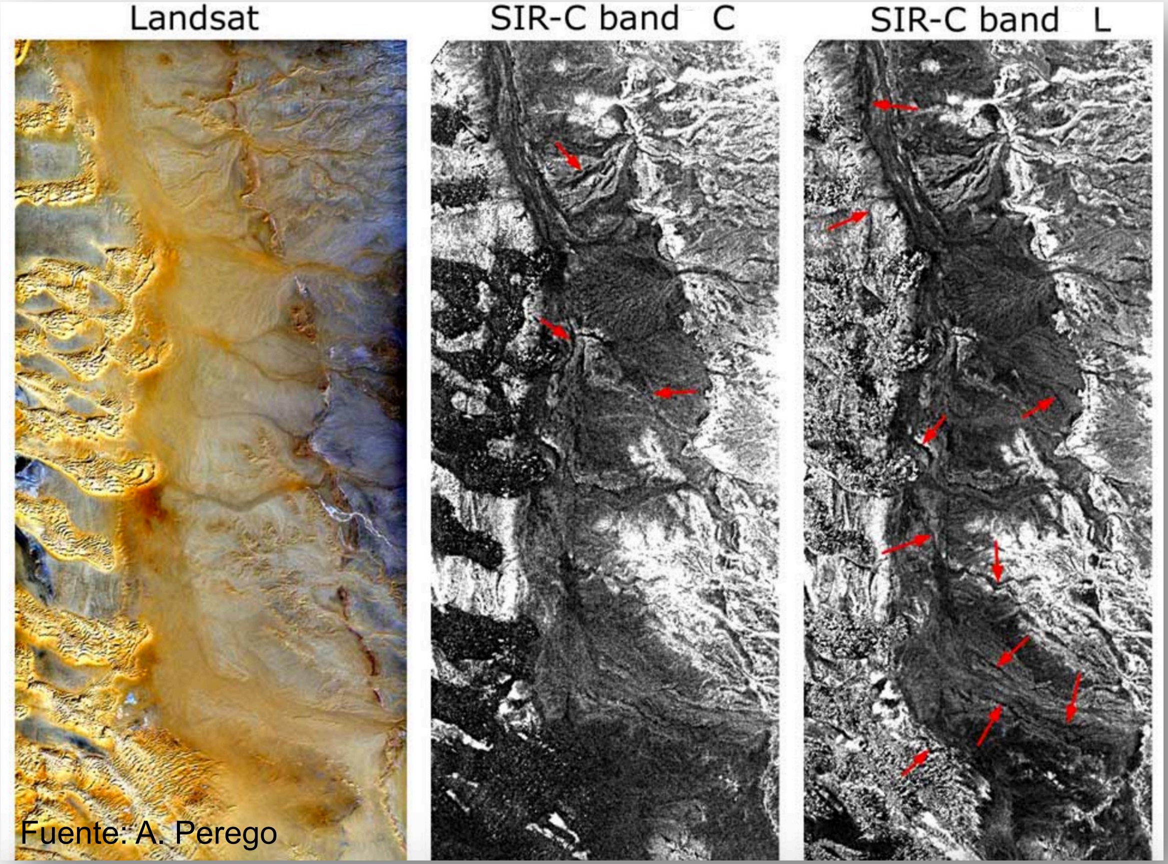
Penetration as a Function of Wavelength



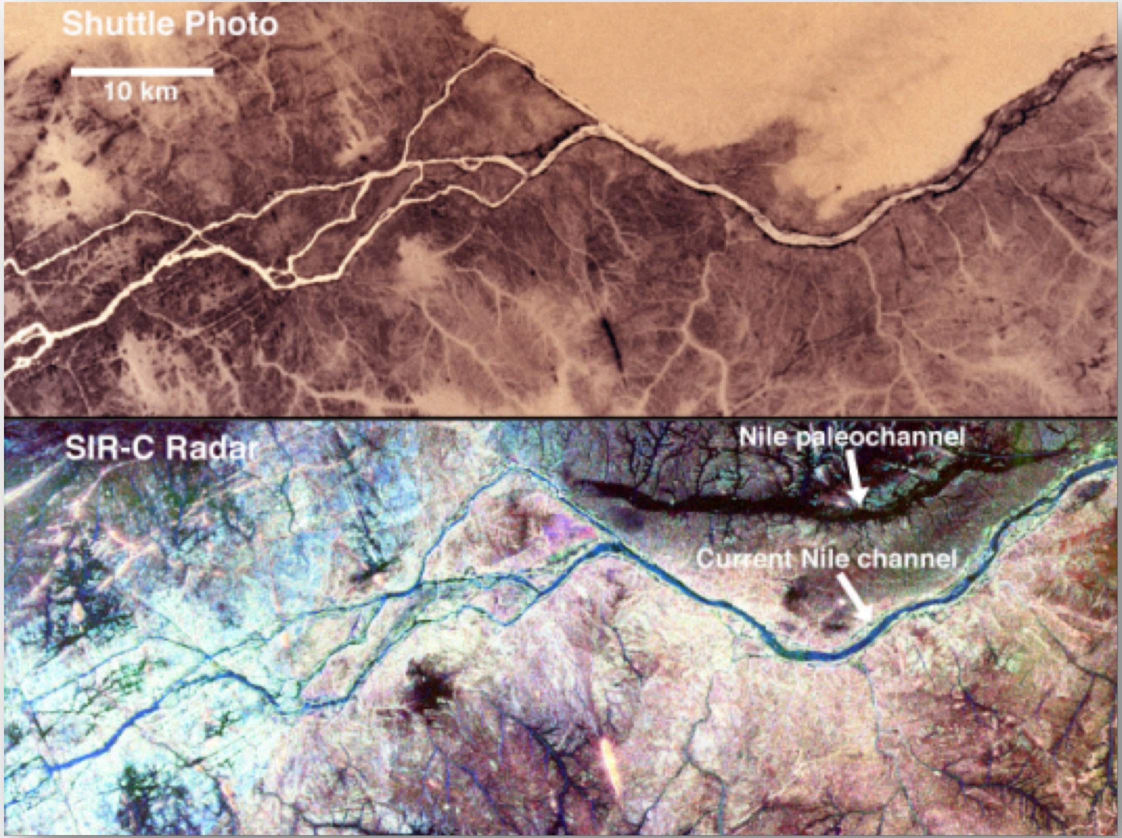
Depending on the frequency and polarization, waves can penetrate into the vegetation and, on dry conditions, to some extent, into the soil (for instance dry snow or sand). Generally, the longer the wavelength, the stronger the penetration into the target. With respect to the polarization, cross-polarized (VH/HV) acquisitions have a significant less penetration effect than co- polarized (HH/VV) one.

Example: Radar Signal Penetration into Dry Soils

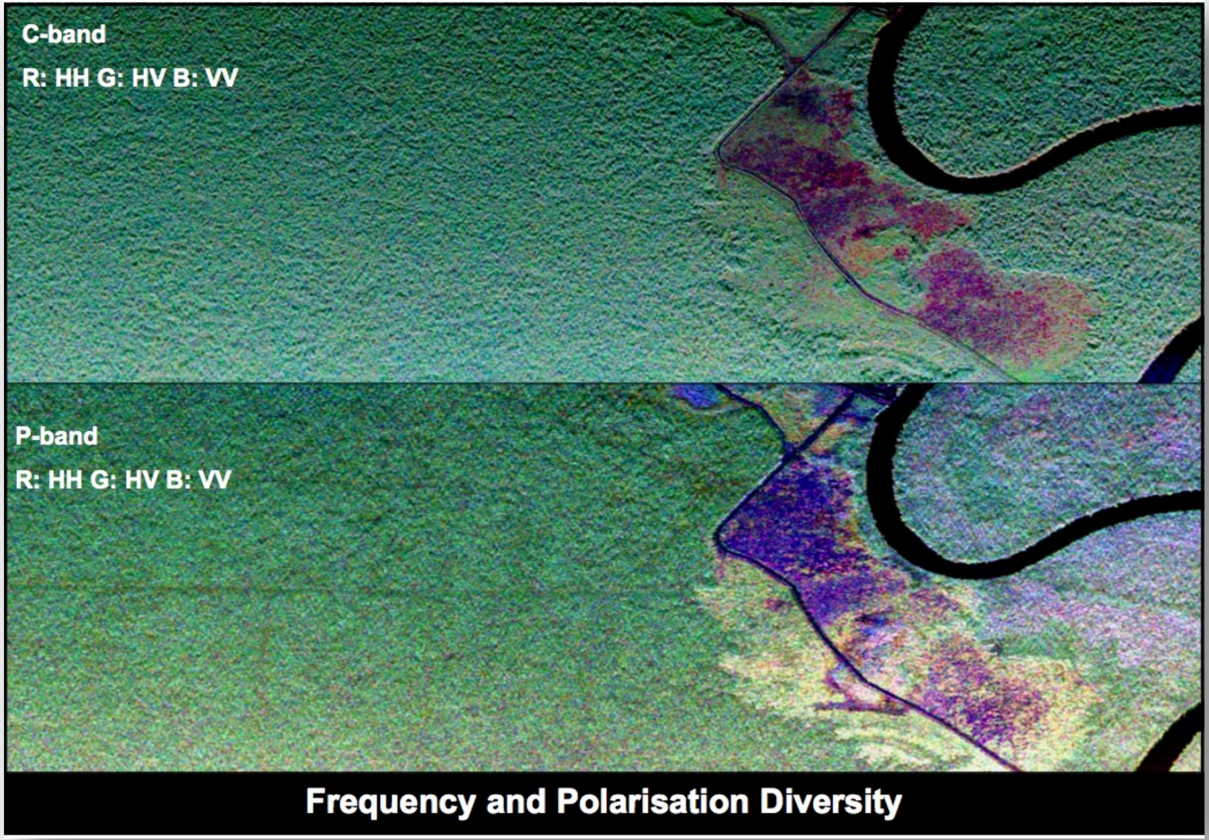
Different satellite images over southwest Libya. The arrows indicate possible fluvial systems.



Example: Radar Signal Penetration into Dry Soils



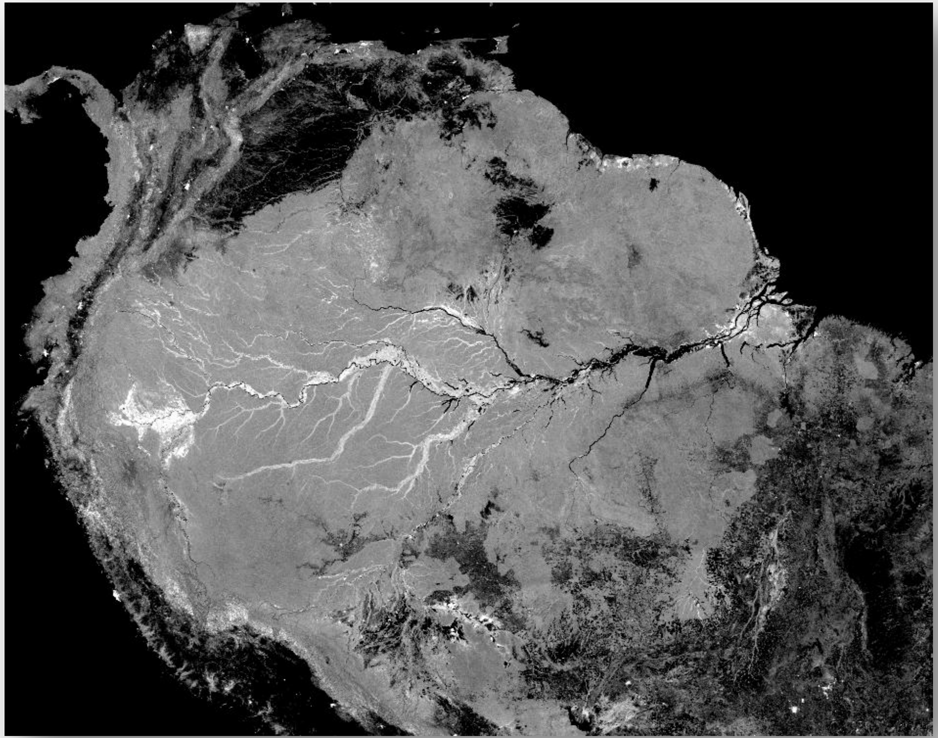
Example: Radar Signal Penetration into Vegetation



Example: Radar Signal Penetration into Wetlands

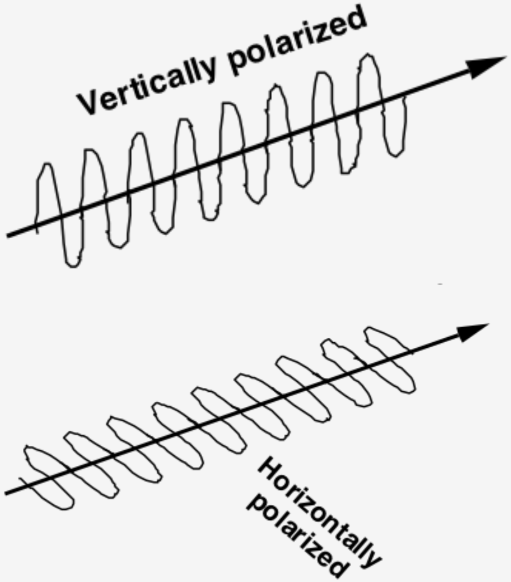
- L-Band is ideal for the study of wetlands because the signal penetrates through the canopy and can sense if there is standing water underneath.
- Inundated areas appear white in the image to the right.

SMAP radar mosaic of the Amazon



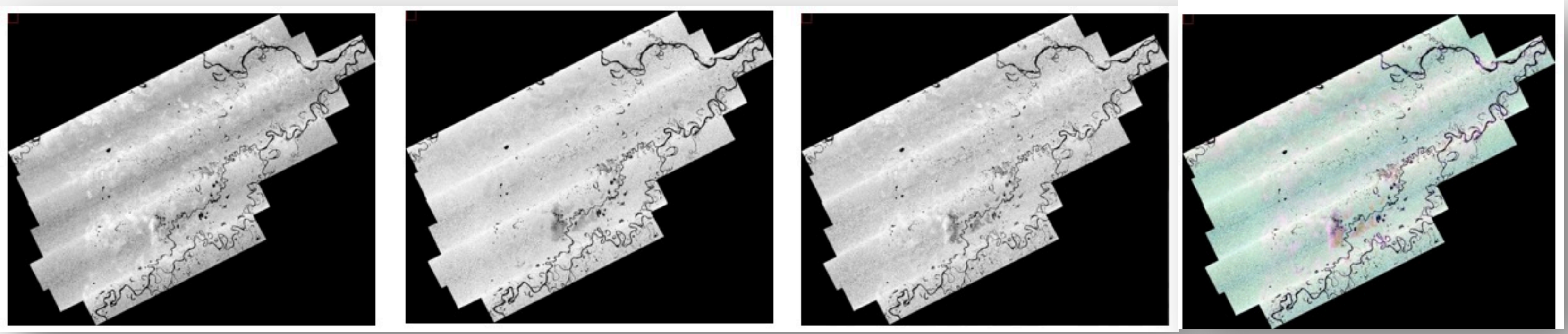
Radar Parameters: Polarization

- The radar signal is polarized (usually horizontally or vertically)
- The polarizations are controlled usually between H and V:
  - HH: Horizontal Transmit, Horizontal Receive
  - HV: Horizontal Transmit, Vertical Receive
  - VH: Vertical Transmit, Horizontal Receive
  - VV: Vertical Transmit, Vertical Receive
- “Quad-Pol Mode- when all four polarizations are measured.
- Different polarizations can be used to determine physical properties of the object observed.



Example of Multiple Polarizations for Vegetation Studies

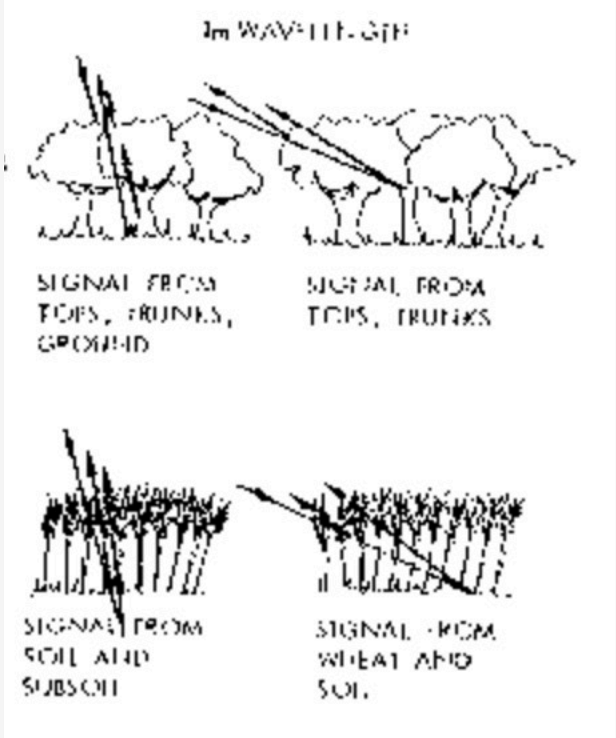
Pacaya-Samiria Forest Reserve in Perú
Images from UAVSAR (HH, HV, VV)



UAVSAR
(HH, HV, VV)

Radar Parameters: Incidence Angle

- Incidence Angle: is the angle between the direction of illumination of the radar and the Earth’s surface plane. Depending on the height of the radar sensor above the surface of the Earth, the incidence angle will change in the range direction. This is why the geometry of an image is different from point to point in the range direction.
- Local incidence angle: that accounts for local inclination of the surface. The incidence angle influences image brightness.



Questions

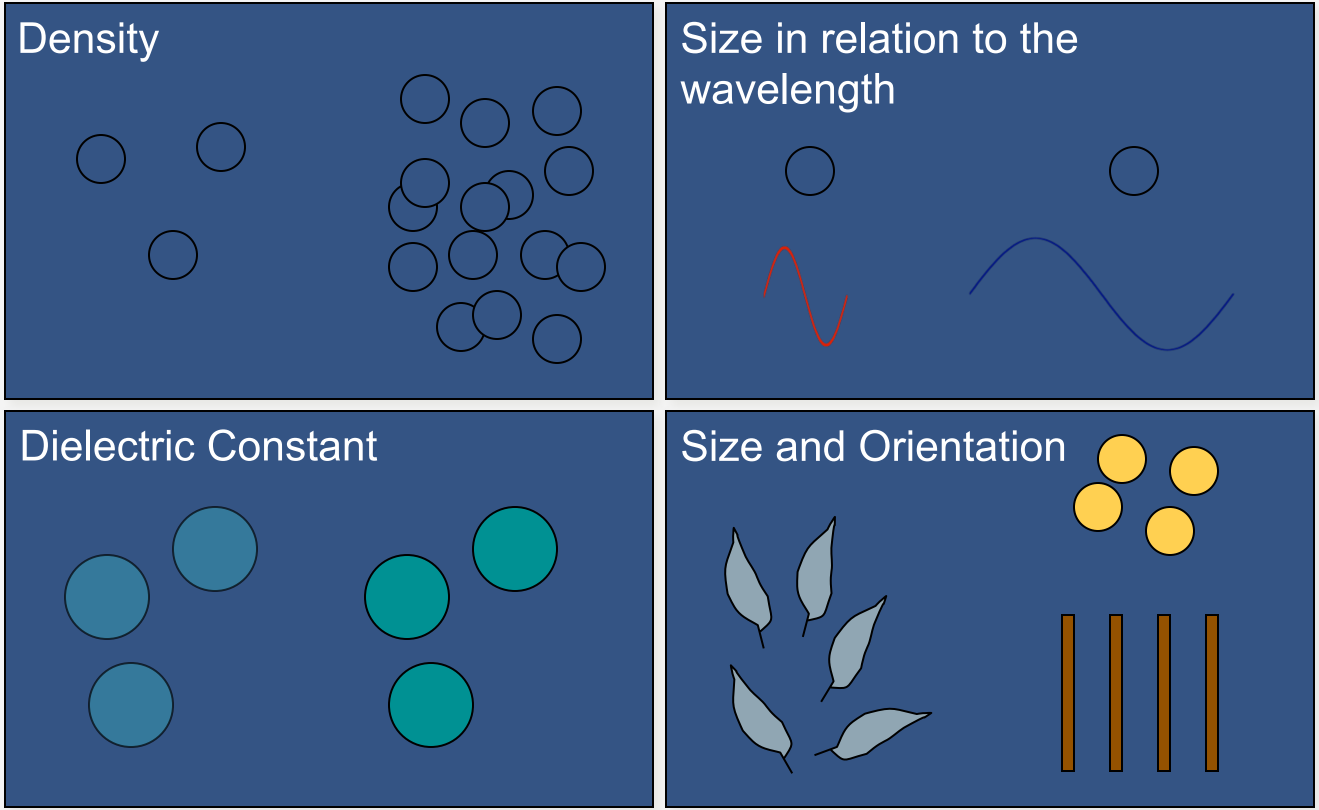
1. What are the advantages of radar sensors?
2. What are three main radar parameters that need to be considered for a specific study?
3. What is the relationship between wavelength and penetration?
4. What’s the usefulness of having different polarizations?
5. What’s the effect of varying incidence angle?

Backscattering Mechanisms of the Radar Signal

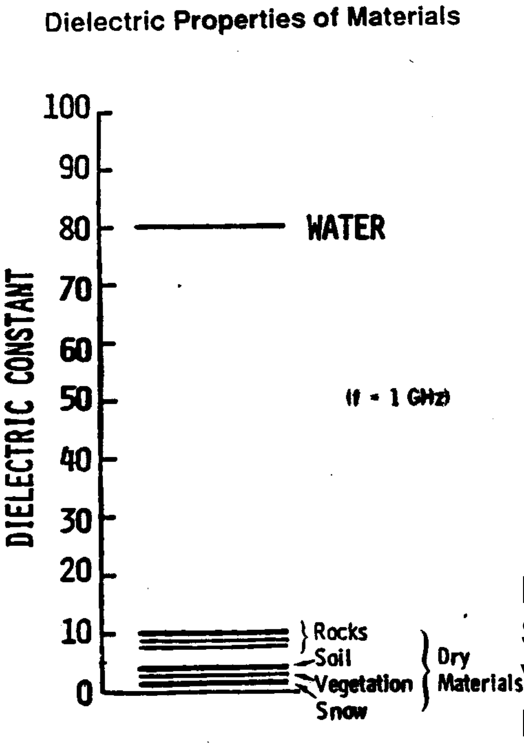
Radar Backscatter

- The radar echo contains information about the Earth’s surface, which drives the reflection of the radar signal.
- This reflection is driven by:
  - The frequency or wavelength: radar parameter
  - Polarization: radar parameter
  - Incidence angle: radar parameter
  - Dielectric constant: surface parameter
  - Surface roughness relative to the wavelength: surface parameter
  - Structure and orientation of objects on the surface: surface parameter

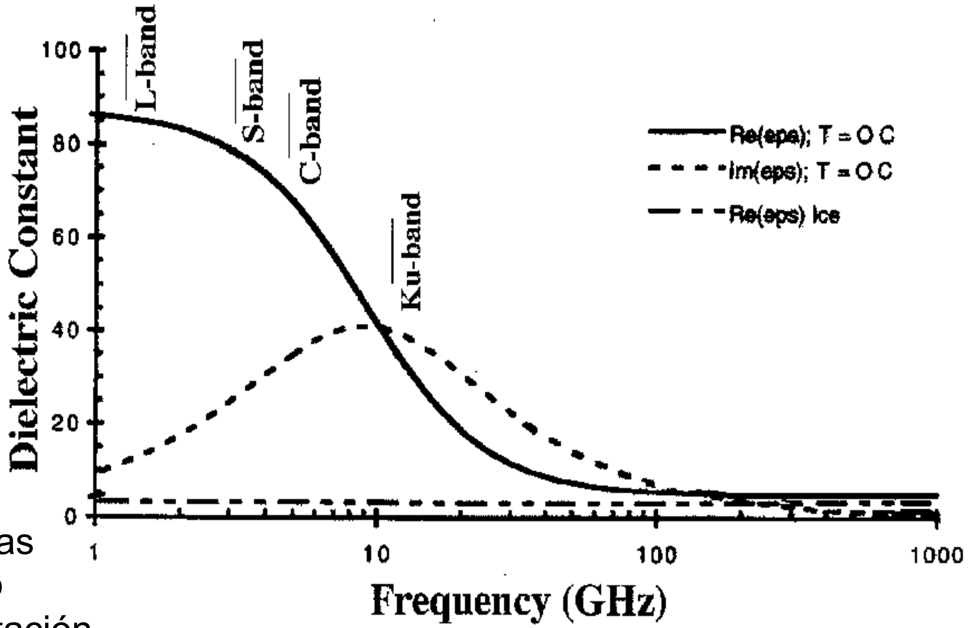
Backscattering Mechanisms



Surface Parameters: Dielectric Constant

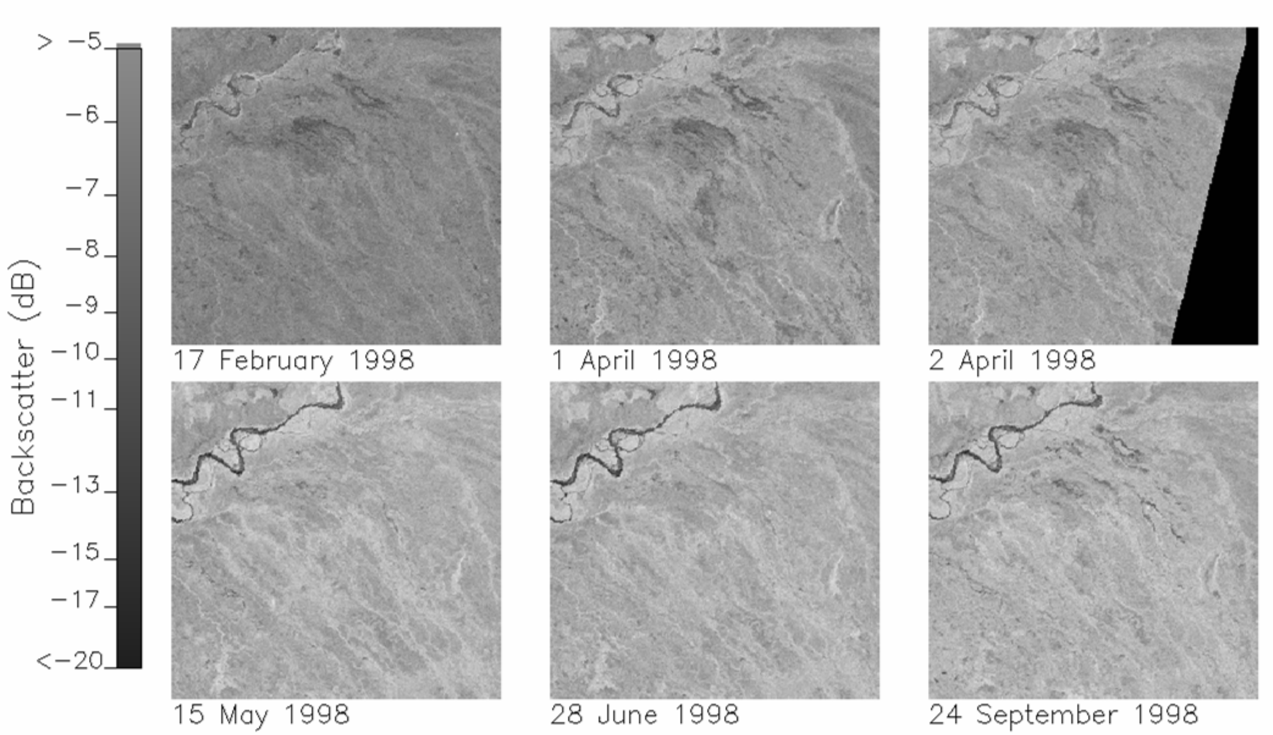


Piedras
Suelo
Vegetación
Nieve



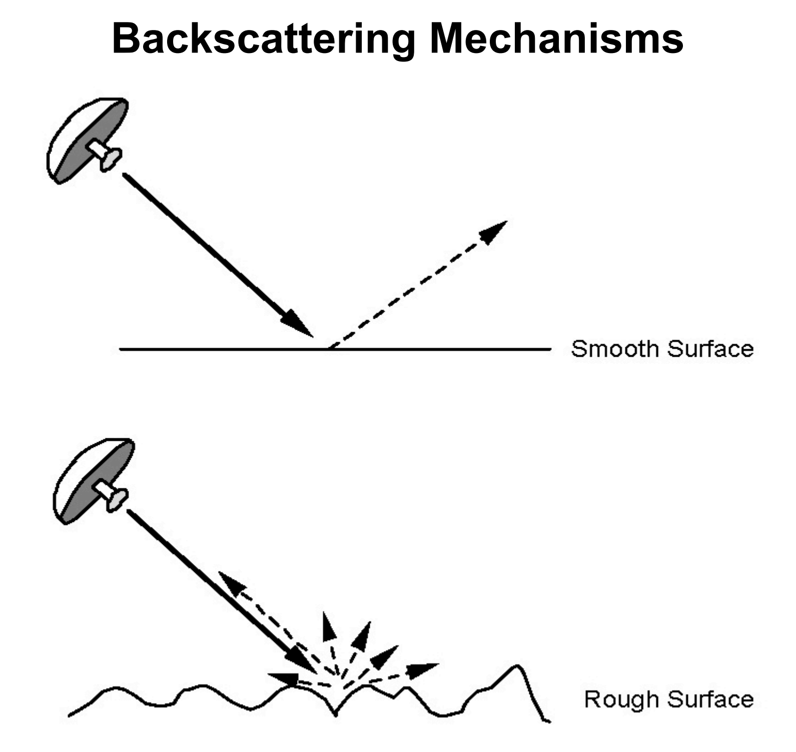
Dielectric Properties of the Surface and its Frozen or Thawed State

During the land surface freeze/thaw transition there is a change in dielectric properties of the surface, which cause a notable increase in backscatter,

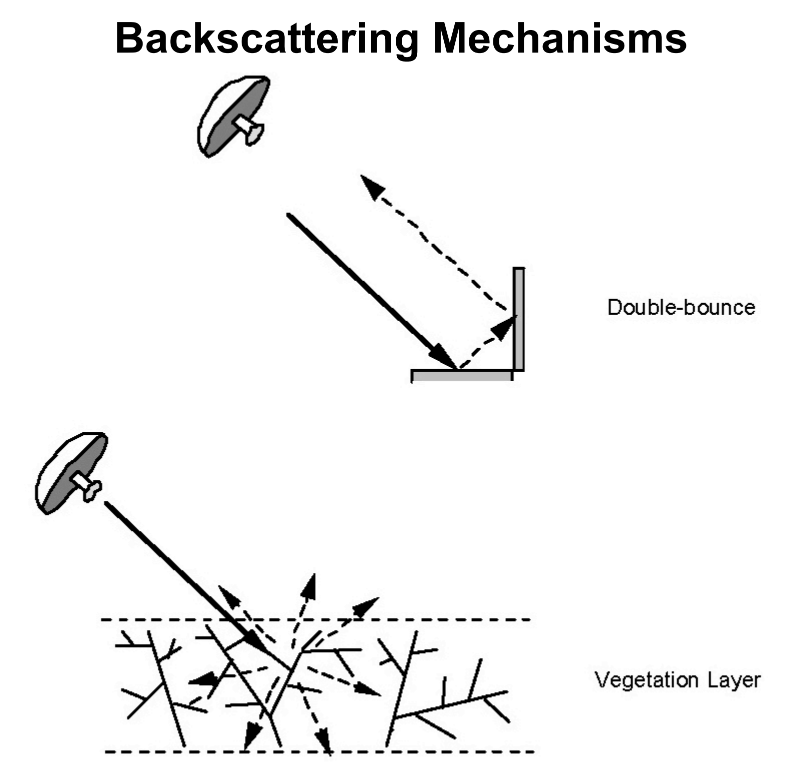


Radar Backscatter Sources: Part 1

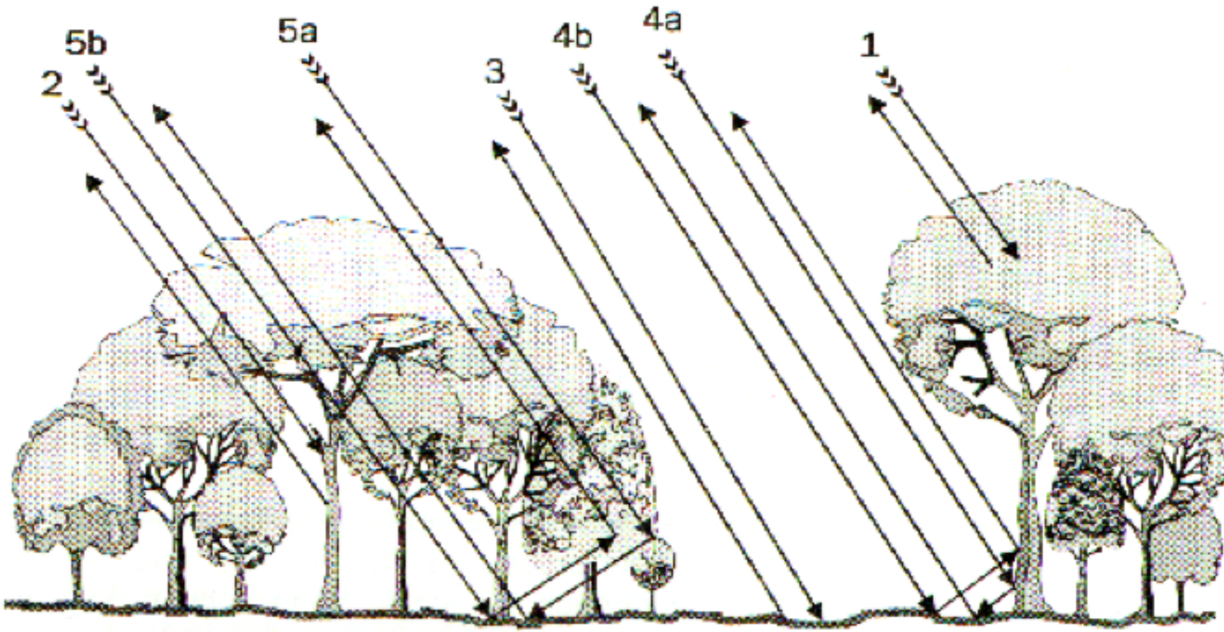
- The radar signal is primarily sensitive to surface structure.
- The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear on the image.



Radar Backscatter Sources: Part 2



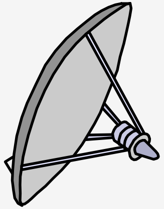
Radar Backscatter Sources: Part 3



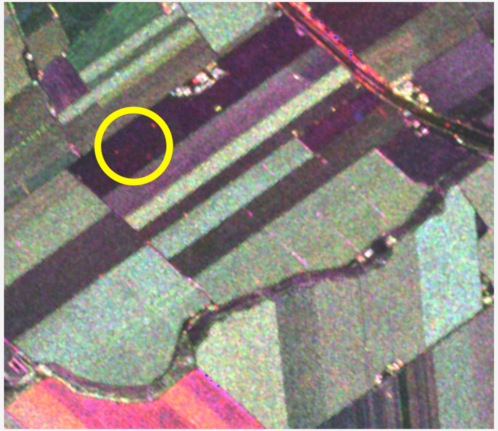
Dominant backscattering sources in forests: (1) crown volume scattering, (2) direct scattering from tree trunks, (3) direct scattering from the soil surface, (4a) trunk - ground scattering, (4b) ground - trunk scattering, (5a) crown - ground scattering, (5b) ground - crown scattering.

Radar Interaction Types

Mirror like reflection (specular reflection)



Pixel Color



Smooth, level surface
(water, road)

Salinas Valley, California
Octubre 24, 1998
L-Band Image

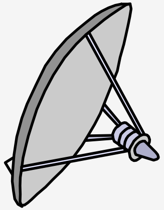
No reflections/echo

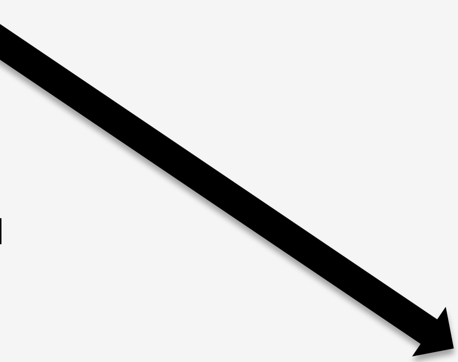
HH CS VV

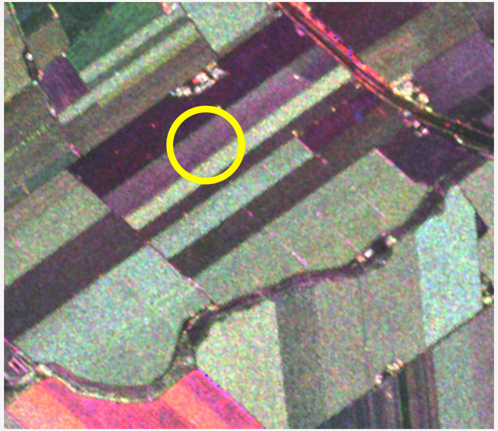
Source: Natural Resources Canada

Radar Interaction Types

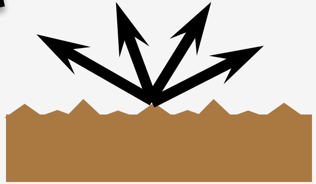
Rough Surface Reflection





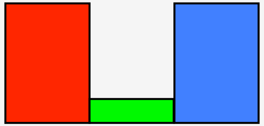


Pixel Color



Rough bare surface

Salinas Valley, California
Octubre 24, 1998
L-Band Image

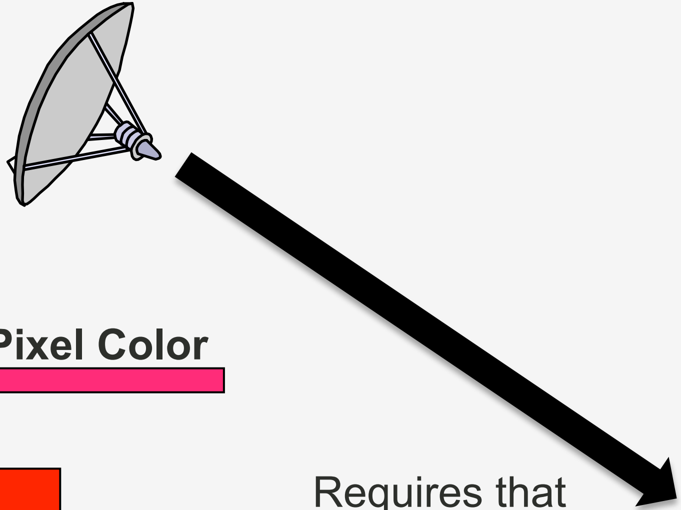


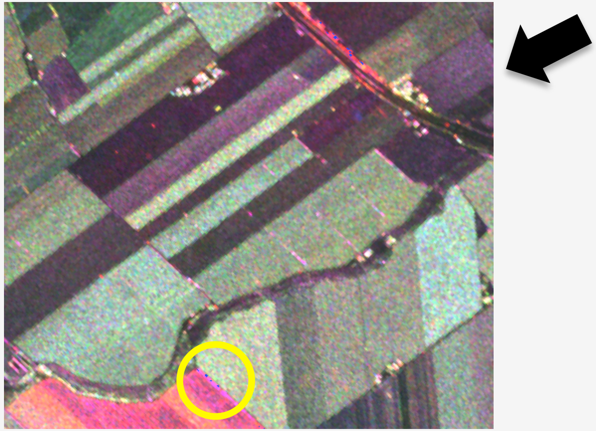
HH CS VV

Source: Natural Resources Canada

Radar Interaction Types

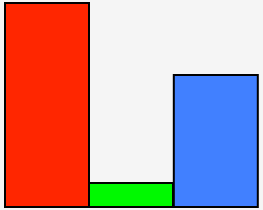
Furrowed Surface Reflection



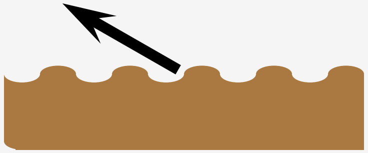


Iluminación

Pixel Color



Requires that rows be perpendicular to radar illumination



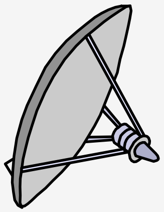
Furrowed Field

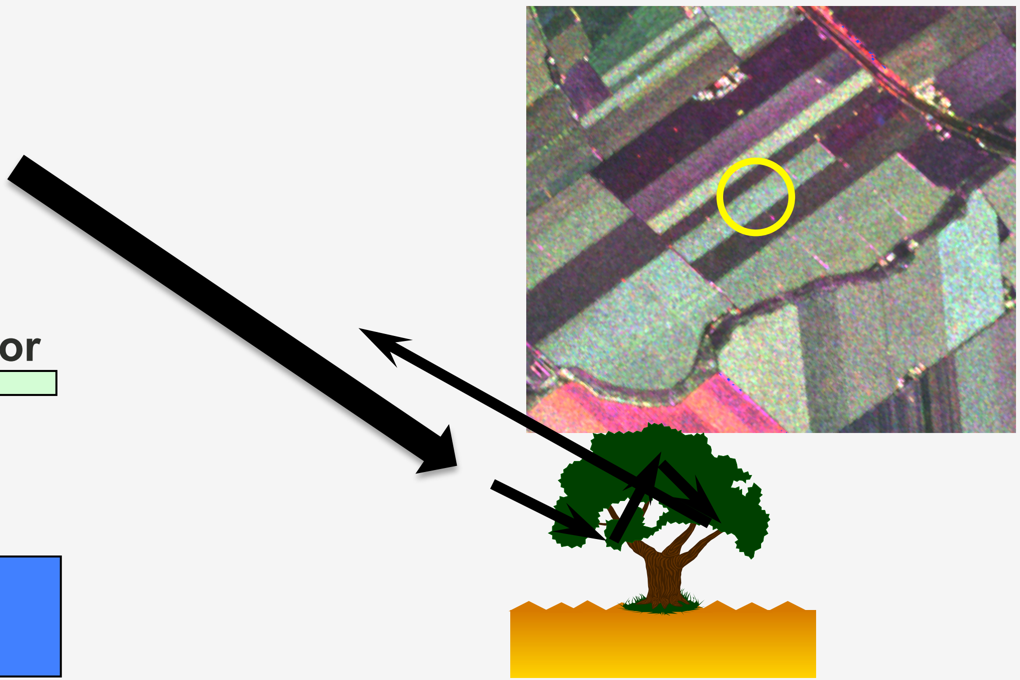
Salinas Valley, California
Octubre 24, 1998
L-Band Image

Source: Natural Resources Canada

Radar Interaction Types

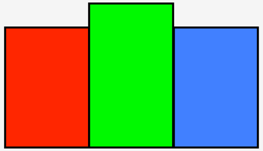
Volume Scattering by Biomass





Vegetation over Soil

Pixel Color

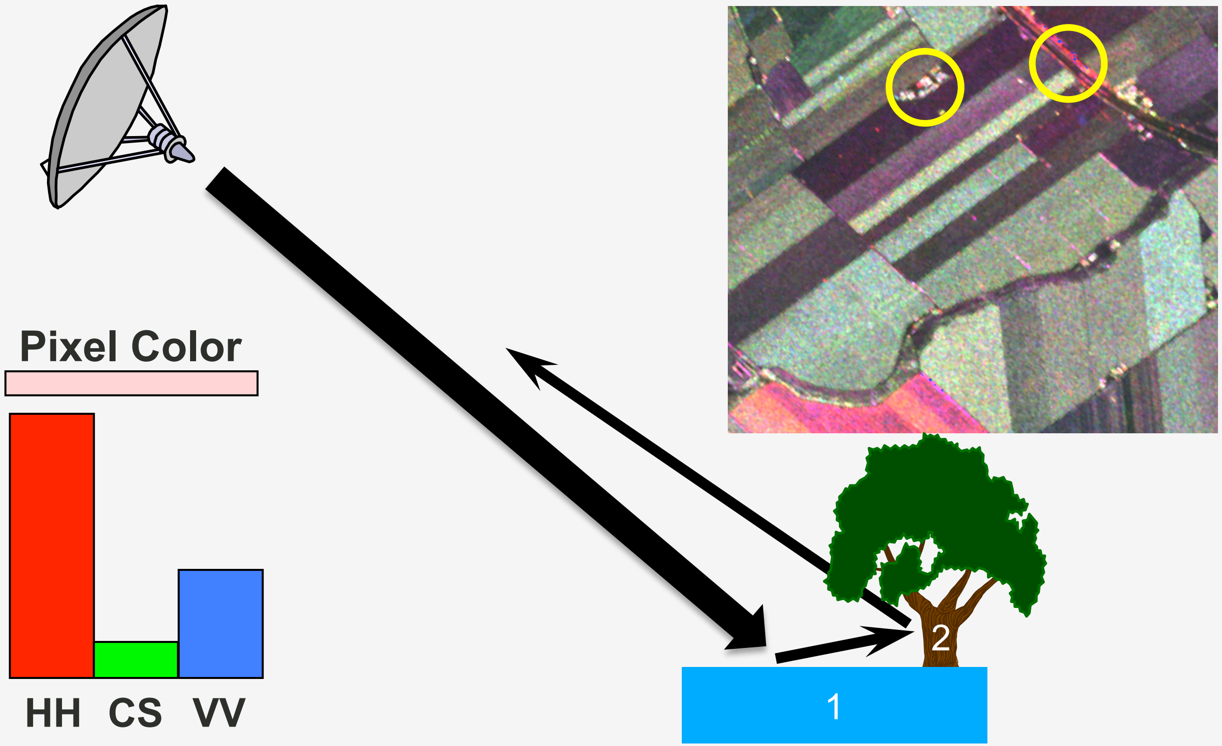


Source: Natural Resources Canada

Salinas Valley, California
Octubre 24, 1998
L-Band Image

Radar Interaction Types

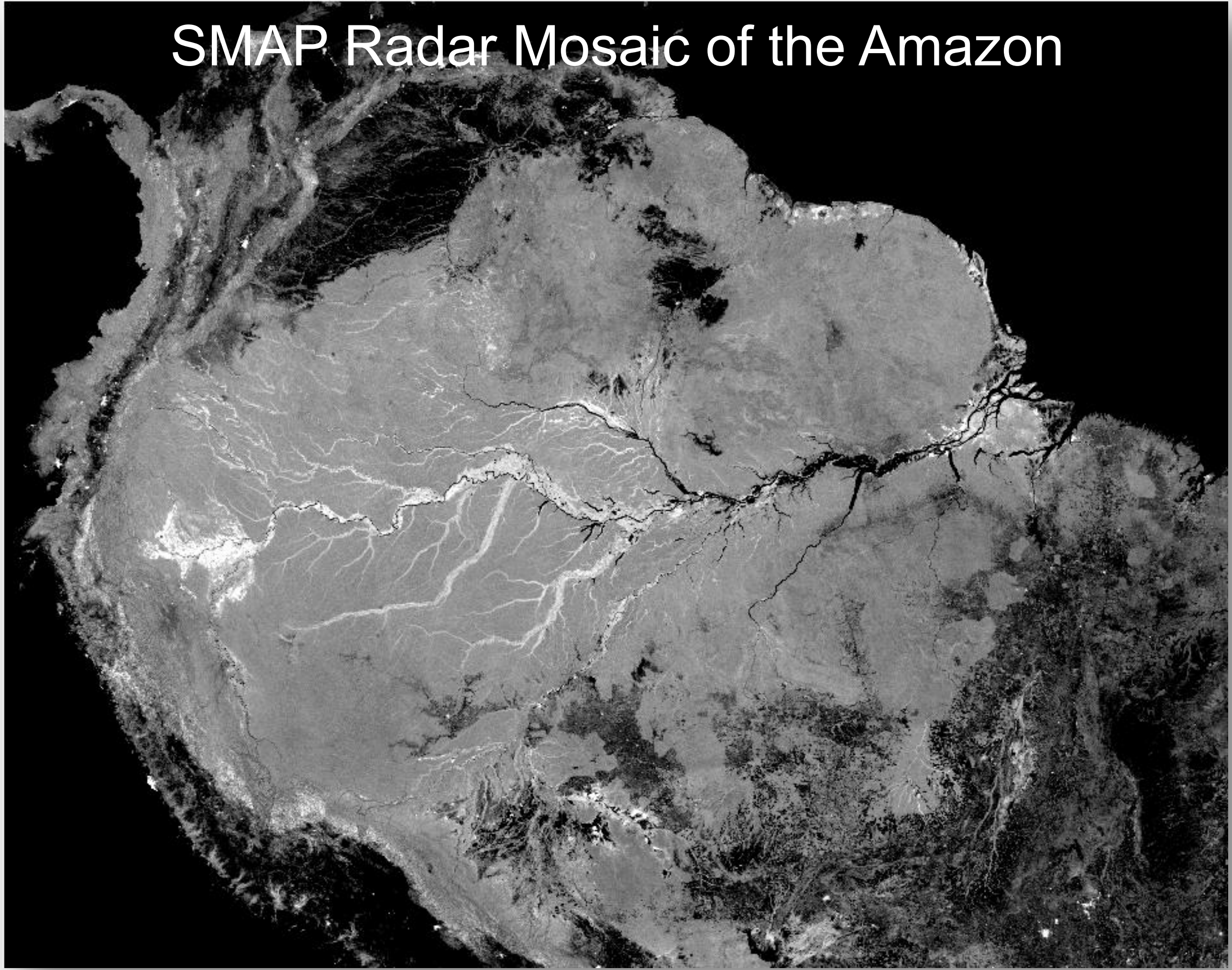
Double Bounce Reflection



Source: Natural Resources Canada

Salinas Valley, California
Octubre 24, 1998
L-Band Image

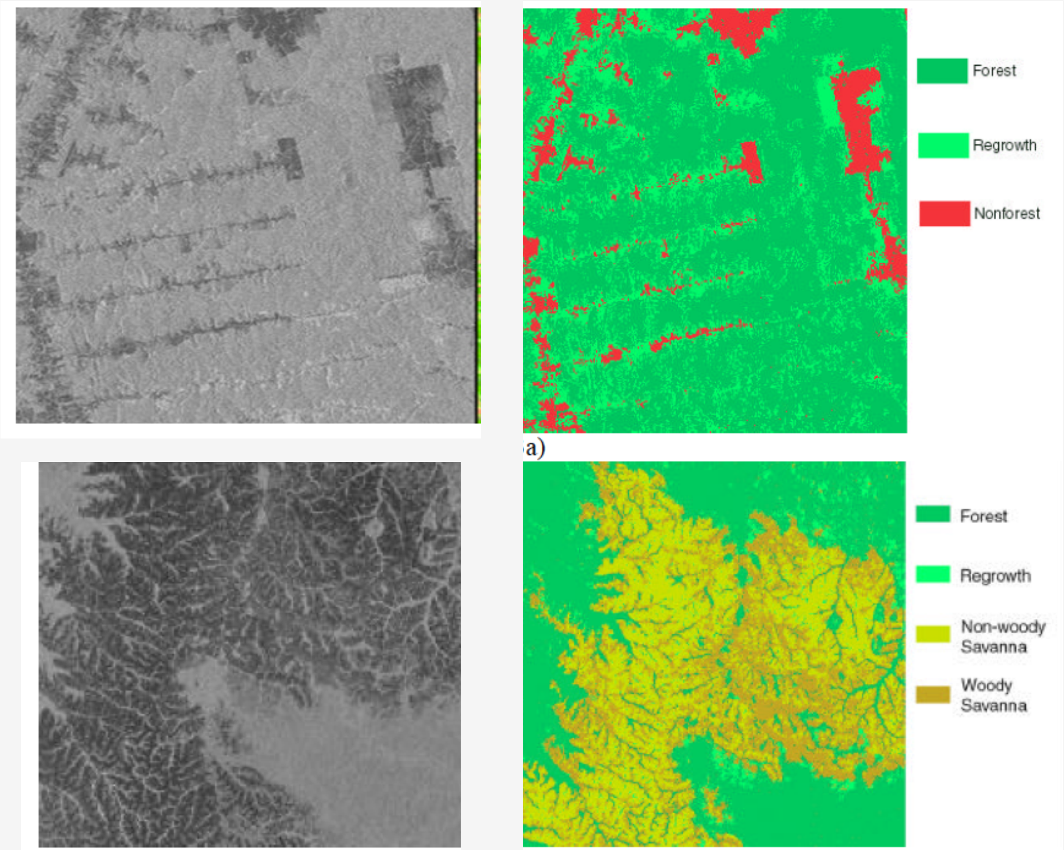
SMAP Radar Mosaic of the Amazon



Example: Detection of Oil Spill on Water

UAVSAR (2 metros)
HH, HV, VV

Example: Landcover Classification

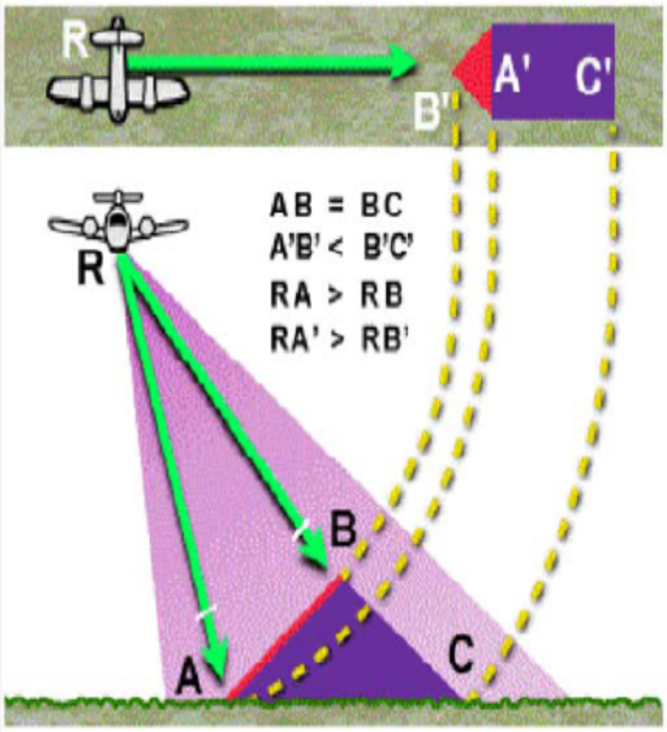


Brazil
JERS-1 L-band
100 meter resolution

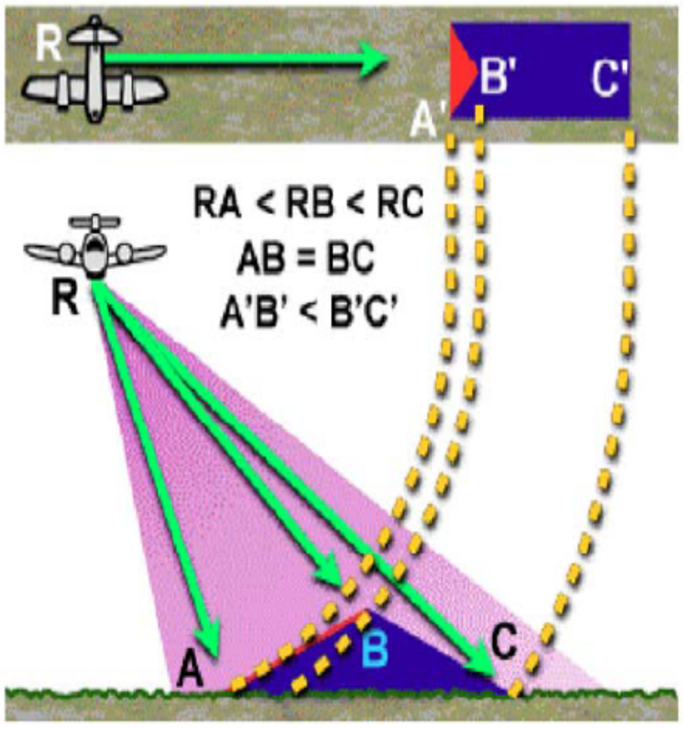
Geometric and Radiometric Distortion of the Radar Signal

Geometric Distortion

Layover



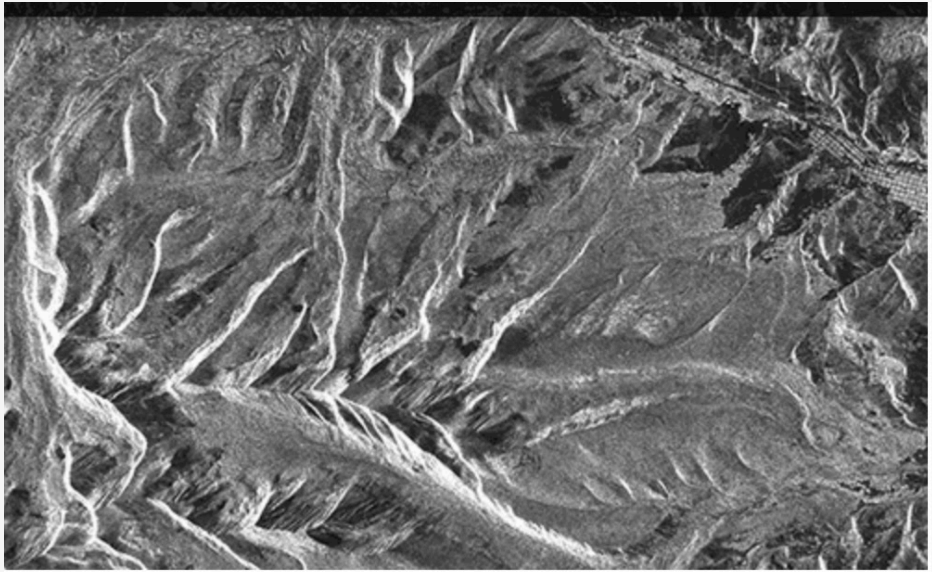
Foreshortening



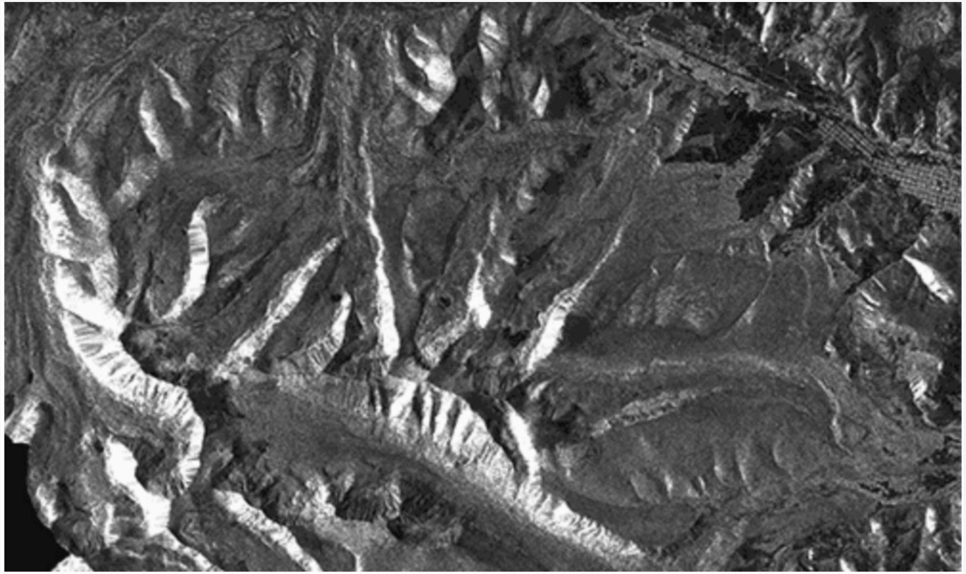
Source: Natural Resources Canada

Foreshortening

Before correction

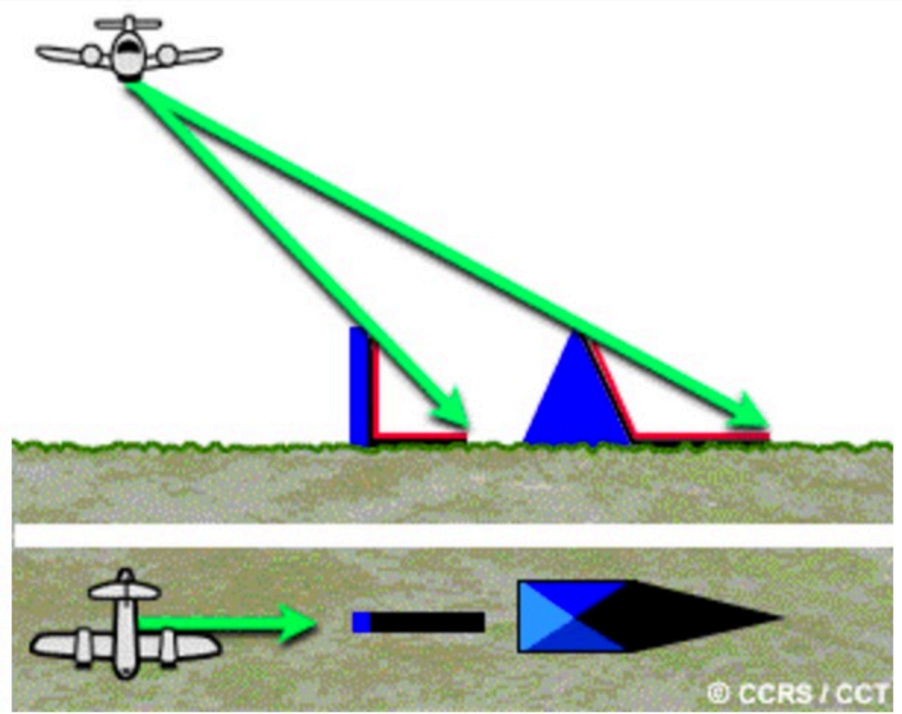


After correction



Source: ASF

Shadow

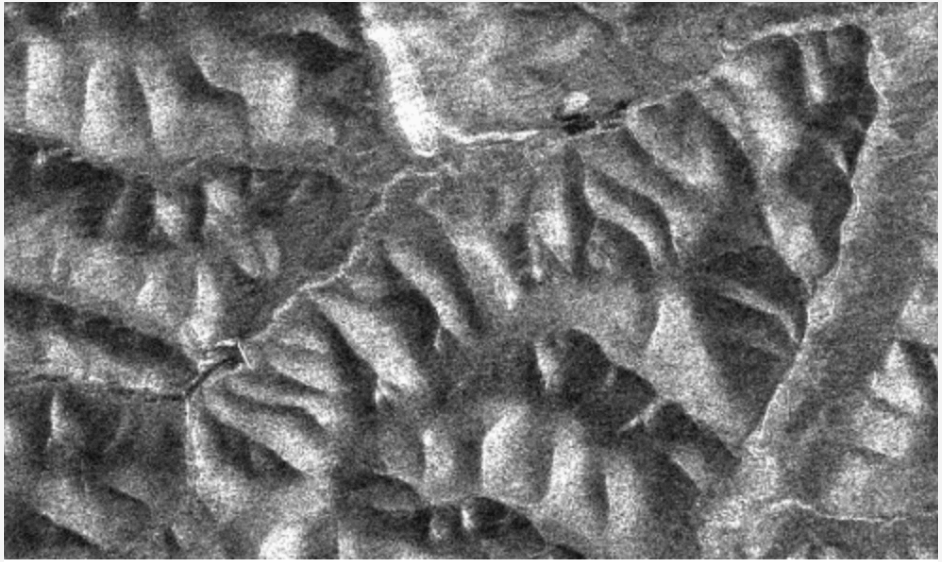


Source: Natural Resources Canada

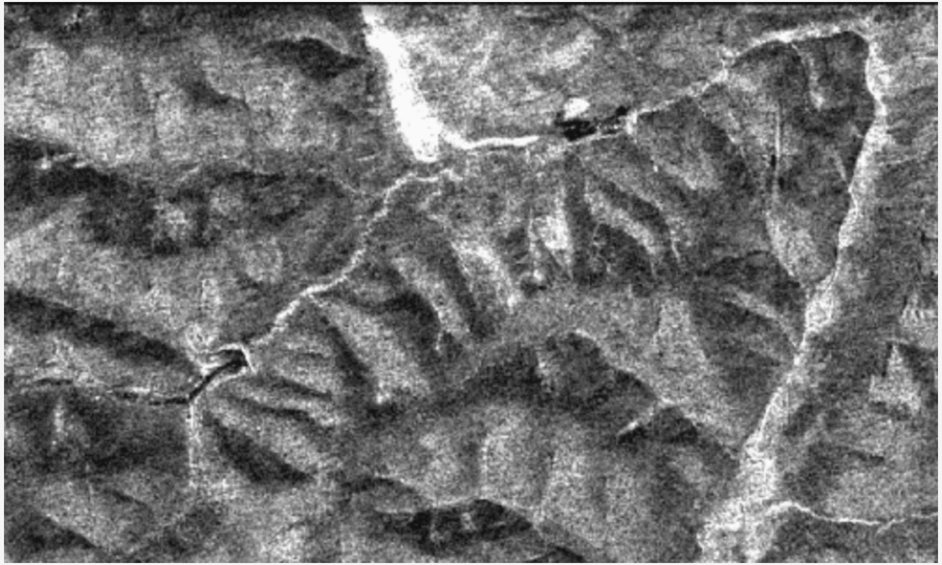
Radiometric Distortion

The user must correct for the influence of topography on backscatter. For example, this correction eliminates high values in areas of complex topography.

Before correction



After correction



Source: ASF

Radar Data from Different Satellite Sensors

Sensor Name	RADARSAT-2	Sentinel-1A	RISAT-1
Agency	Canadian Space Program (CSP)	European Space Agency (ESA)	Indian Space Research Organization (ISRO)
Instrument	C-band SAR (5.4 GHz)	C-band SAR (5.4 GHz)	C-band SAR (5.35 GHz)
Incidence Angle	Side-looking, 15-45° off-nadir	Side-looking, 15-45° off-nadir	36.85°
Polarization	HH, HV, VV, & VH	(VV & VH) or (HH & HV)	HH & HV
Sensor Height at Equator	798km	693km	542km
Orbit	Sun Synchronous (dusk/dawn)	Sun Synchronous (dusk/dawn)	Sun Synchronous (dusk/dawn)
Revisit Time (Orbit Repeat Cycle)	24 days	12 days	25 days

Datos de Radar de Diferentes Satélites

Sensor Name	RADARSAT-2	Sentinel-1A	RISAT-1
Resolution	100m	5m x 20m	~25m
Swath Width	500km (ScanSAR mode)	250km (IWS mode)	115km (MRS)
Mean Local Time	6:00 a.m. descending	6:00 a.m. descending	6:00 a.m.
Launch	14 Dec 2007	3 April 2014	26 Apr 2012
Planned Lifetime	7 years minimum	7 years	5 years

Questions

1. What are the two surface parameters to which radar is sensitive?
2. Which are the three main backscattering mechanisms?
3. What type of distortions do radar images have?
4. Which are the geometric distortions?
5. What type of products can you generate from radar images?
6. How can you use radar images for your specific application?